

## Archimedes: a feasibility study of an experiment to weigh the electromagnetic vacuum

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Archimedes is a feasibility study of a future experiment to ascertain the interaction of vacuum fluctuations with gravity. The experiment should measure the force that the earth's gravitational field exerts on a Casimir cavity by using a small force detector. Here we analyse the main parameters of the experiment and we present its conceptual scheme, which overcomes in principle the most critical problems.

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### 1. Introduction

The cosmological constant problem is among the main fundamental unsolved questions of modern physics. The vacuum energy density resulting from quantum field theory is enormously larger than the value constrained from General Relativity, by considering the radius of our universe and its accelerated expansion. Although there is a long list of detailed and important theoretical works, e.g.,<sup>1-3</sup> a real agreement has not been reached on this topic. The predicted effect is such that only in the last few years, the improved techniques for high temperature superconductors and small forces' detection have shown a way to follow a real experimental path.<sup>4</sup>

### 2. Weighing the vacuum energy

The idea is to weigh the vacuum energy stored in a rigid Casimir cavity formed by parallel conducting plates. If the vacuum energy does interact with gravity, a force directed upwards acts on the cavity and can be interpreted as the lack of weight of the modes expelled by it, similarly to the Archimedes buoyancy of a fluid. The force is equal to:<sup>5</sup>

$$\vec{F} = -\frac{|E_C|}{c^2} \vec{g} = -\mathcal{A} \frac{\pi^2 \hbar}{720 a^3} \frac{\vec{g}}{c} \quad (1)$$

where  $E_C$  is the vacuum energy stored in the cavity,  $a$  is the gap between the plates and  $\mathcal{A}$  is their surface,  $c$  is the speed of light and  $\vec{g}$  is the earth's gravitational acceleration directed downwards.

The measurement principle is to modulate the Casimir cavity weight by periodically changing its vacuum energy. This can be obtained by modulating the reflectivity of the plates. Using superconducting plates and moving around their transition temperature can be an effective method to change their reflectivity.<sup>5</sup> The use of cuprates like YBCO, a type-II high layered  $T_c$  superconductor can be suitable for our purpose. The cuprates are formed by a huge number of natural stacks of superconductor layers separated by dielectric layers and they can be modeled as multi-Casimir cavities that provide a big energy change during transition. Even though a complete study is still lacking, and it is one of the problems to be faced inside the Archimedes project, the expected amplitude  $F$  of the modulated force is of order  $F \sim 10^{-16}N$ .

### 3. The experiment

Either the gravitational wave detectors or the balances could be used for detecting the Archimedes force.<sup>5</sup> However, the detection bandwidth typical of the thermal processes in the periodical transition from normal to superconducting state is in the region of 1-100 mHz, so that the balances are more suitable for this application.

A very sensitive balance requires an excellent isolation from the seismic noise at the very low frequency regime of 1-100 mHz. The use of a seismic-attenuation device dealing with an inverted pendulum and a suitably tuned resonator hung to it can fulfill the requirements. Another challenging point is the thermal modulation around the  $T_c$  transition temperature. Only the radiative mechanism must be used to remove or add thermal energy to the sample, because it must be isolated from any external interaction that could add energy other than the vacuum one. Thermal times depend on the thermal properties of chosen materials and their geometry, and since the radiative exchange is privileged, an optimization is needed to reduce the transition times and increase the frequency bandwidth. To follow all the requirements both the thermal and the mechanical design must proceed together.

### 4. Conclusion

The Archimedes experiment aims at verifying the feasibility to measure the weight of the vacuum. Three crucial points are focused with this project, the construction of a balance sensitive to forces at the level of  $10^{-16} N$ , a thermal modulation system using only a radiative mechanism, and the detailed study of high  $T_c$  superconducting systems as the main source of vacuum energy.

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